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APPLICATION OF STATISTICAL ANALYSIS TO RADIO TRANSMISSION PROBLEMS.*

The radio laboratory of the Bureau of Standards has, in a number of cases, had the problem of analyzing a large amount of complex data obtained as a result of tests conducted for the purpose of investigating radio transmission phenomena. The wide distribution of observers and the large number of variables contained in the data require the use of rapid methods of analysis. With the cooperation of the Bureau of the Census it has been possible to make a comprehensive statistical analysis of such data with a minimum expenditure of time by the use of the tabulating machines with which the Bureau of the Census is equipped.

Nature of Applications of Method.-- The first radio problem in which such an analysis was made by the Bureau was the investigation of signal fading conducted during the years 1920 and 1921 in cooperation with the American Radio Relay League (reported in the following articles, "The Bureau of Standards - A.R.R.L. Fading Tests," by S.Kruse, QST, 4, Sept., Nov., Dec., 1920; "Radio Signal Fading Phenomena," by J.H.Dellinger and L.E.Whittemore, Journal Washington Academy of Sciences, 11, p.245, 1921; "Final Report on the Fading Tests," QST, 7, p.29 of August, p.23 of Sept., 1923). A network of observing stations distributed over the eastern part of this country and Canada recorded, on each test night, the variation in the strength of signals received from designated transmitting stations and forwarded these records to the Bureau of Standards for analysis and interpretation.

An investigation of the transmission distance range of radio broadcasting stations has been in progress since 1922, the results of which are being analyzed in a similar way. The reports are secured in such a form as to be readily transferable to tabulating machine cards as described below in the case of signal fading.

Statistical work of similar character with the aid of the tabulating machine has been done for many years by workers in sciences other than radio communication. It is the purpose of this pamphlet to describe the actual procedure followed in analyzing a specific kind of radio data so that others wishing to employ the method may easily adapt it to radio problems.

In the radio fading tests, uniform record cards were prepared for each observation by every observer taking part. These cards

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(See Fig. 1) contained such information as general reception conditions, intensity of signals received from the transmitting station of the system and the presence or absence of "atmospherics." From descriptions of their stations sent in by each observer in the early stages of the investigation additional information of a more or less invariable character was obtained.

The Tabulating Machine.-- Several types of electric tabulating machines are in use all of which are designed to compile, classify and analyze statistical information. The original data are transferred to cards by means of punched holes, which permit the machine electrically and automatically to classify and aggregate the various items recorded. The records obtained are capable of positive proof and are immediately available. Three machines are used in this work, a key punch, a sorting machine, and a tabulating or counting machine.

The key punch is manually operated and is used to transfer the data to the tabulating machine cards. Figure 1 shows a standard card used in these machines. The perforations represent classified information that can be readily compiled to meet the particular need and this translation of written details into numerals enables the adoption of a rapid and elastic method of making studies of the same figures from different points of view. For example, suppose it is desired to learn what effect the presence of clouds during transmission has on the fading of signals. It is possible by this method not only to examine the data with reference to clouds present at the transmitting station but also to consider the presence of clouds at each receiving station individually or simultaneously at all points of the recording system. It is possible to do this with each factor entering into the problem, the tabulation of any conceivable combination of the various factors being made quickly and accurately.

The sorting machine is used in the process of sorting the information contained by the cards into any desired groups or classes.

The tabulating machine counts the cards and at the same time obtains any total or subtotal of the information desired. All of these machines operate at high speed and with remarkable accuracy.

Preparation of the Data.-- All data entering into the analysis must be coded, numbers being assigned according to a prearranged schedule. At the same time that the code numbers are assigned a vertical column (or more columns if necessary) on the standard card is reserved for each variable to be used. (See Fig. 1). This arrangement may be compared to a system of rectangular coordinates. The following table will serve to illustrate how one set of values of a given item was coded:

Table I.

Wave frequency	Code number
1499 kilocycles	1
1428 "	2
1393 "	3
1199 "	4
1033 "	5
999 "	6
908 "	7
799 "	8
576 "	9

The sixth vertical column on the standard card was reserved for wave frequency data. The remaining items were coded in a similar manner and a copy of the complete code used in our work is attached to this paper. (Appendix I and Appendix II give the tabulation codes used in the fading tests and the distance range tests respectively).

Charts consisting of cross-section paper having the same number of vertical columns as the tabulating machine cards were used in the fading test analysis to summarize the data and to serve as a source of information when punching the tabulating machine cards. On the chart each horizontal line represented one record card and supplied the information necessary for punching one tabulating machine card. More than ninety (90) such charts averaging seventy (70) records each were necessary for summarizing the fading test data.

A large part of this labor may be eliminated in work of this kind by having the standard card punched or marked by the observer while in the field. If so desired, the cards could be marked with a pencil in the proper places and the cards sent into the central office for punching and tabulating. Actual punching in the field would necessitate the use of a punching machine by each observer. It would probably be more efficient and generally satisfactory to do all punching in one place where a skilled operator is available.

A method now in use by this Bureau and which is due to Mr. C.M.Jansky, Jr., eliminates a large part of the clerical work attached to the punching of the tabulating machine cards. Each observer is supplied with prepared forms which he uses in reporting the results of his observations. There are tables on the forms which are numbered and, in general, the observer gives the desired information by checking one of the items in each table. Upon receipt, fully filled out, the form is edited and the numbers checked in the various tables are inserted in reserved spaces at the bottom of the sheet. This arrangement permits the transfer of data to tabulating machine cards with a minimum amount of labor.

The Process of Tabulation.-- All cards having been punched they are ready for the sorting and tabulating machines which will automatically count and classify the data on the cards in any way desired. Detailed written instructions are prepared which enable the tabulating machine operator to analyze the data and at the same time enter in spaces provided in these instructions, the totals and subtotals obtained. The work from this point is automatic, it being only necessary to set the tabulating machine to sort the cards according to the information desired. For example, to sort the cards into groups according to wave frequencies used, it would be necessary to set the sorting machine at the sixth column which is the column reserved for wave frequency data. After passing the cards through the machine, nine groups of cards would be obtained and each group would then be counted. The result of the above operation would appear as follows:

Wave frequency, kilocycles	Total number of records
1499	532
1428	000
1393	354
1199	2701
1033	000
999	97
908	000
799	1965
576	35

The above operation takes into account only the information relating to wave frequency without regard to the other factors. An example of sorting and counting when two or more factors are considered simultaneously is given in what follows.

We will suppose that it is desired to compare all of the transmitting stations taking part in the tests with regard to the uniformity of the intensity of signals received from them. The first step would be to sort the cards into sixteen groups (since there were sixteen transmitting stations), each group containing all the records taken on a particular transmitter. The number of cards in each group would then be counted using the tabulating machine for that purpose.

Each of these sixteen groups is now separated into two subgroups, the one containing all records reporting no fading or slight fading and the other group containing all records reporting bad fading. The number of cards in each of these groups is also counted. The results of this sorting would be as follows:

Table 2*

Transmitting Station	Total Records	Bad Fading	No Fading
NSF	1237	210	240
9ZN	668	191	219
1AW	901	291	244

* (Note: Only three of the sixteen stations are listed).

Medium values may be obtained by adding together the extreme values and subtracting this from the total. By means of these values or ones similarly taken, tables may be prepared as an aid to the interpretation of the results. Such a table is shown below in which the values are expressed in percentages of the totals:

Table 3*

Transmitting stations listed according to percentage non-fading signals during fading tests.

Station	% No Fading
1. 8XK (Master oscillator tube)	42.6
2. 9ZN (500-cycle spark)	42.5
3. 2RK	36.1
4. 8ZW	35.4
5. 9ZN (60-cycle spark)	33.8
6. 8XK (Self oscillator tube)	31.8
7. 9LQ	30.9
8. 9ZJ	2773
9. 1AW	27.3
10. 2JU	26.2
11. 8ER	21.8
12. 9AU	21.3
13. 3XF	21.0
14. 1BBL	20.6
15. NSF	19.4
16. WWV	14.6

*A complete set of tables in which are included the results obtained by this method of analysis is given in Scientific Paper No. 476, "A study of radio signal fading," by J.H.Dellinger, L.F.Whittemore, and S.Kruse, obtainable from the Superintendant of Documents, Government Printing Office, Washington, D.C., at ten cents per copy.

A machine has been recently developed and is now commercially available which greatly simplifies analyses such as have been just described. This machine is called a "digit counter." This machine will count the number of cards having ones, the number having twos, the number having threes, etc., punched out in a particular column for a given group of cards passed through the machine. For example, instead of sorting according to the sixth column and then counting the nine groups separately to secure the data given above, the result could be obtained by one operation with a digit counter. If the cards were passed through this machine with the stylus set opposite the sixth column, the total number of records for each wave frequency would be shown on nine of the fourteen counters on the machine.

In addition to the nine digits, this machine will also count

cards having the O, R and X positions punched and also the total number of punched cards passed through the machine. With this machine it is also possible to use cards having more than one hole per column. The possibilities of the digit counter greatly extend the usefulness of tabulating machines in scientific work.

Appendix I.

Radio Fading Test Tabulation Code.

Observing stations:

Observing stations are coded by taking an alphabetical list of their calls and assigning serial numbers beginning with the first station.

Month and Days:

The usual method of coding is used, e.g. 11/12/21.

Wave frequency code:

1 = 1499 kilocycles
2 = 1428 "
3 = 1393 "
4 = 1199 "
5 = 1033 "
6 = 999 "
7 = 908 "
8 = 799 "
9 = 576 "

Receiving region (zones):

1 = N to NE and closer than 250 miles
2 = NE to E " " " " "
3 = E to SE " " " " "
4 = SE to S " " " " "
5 = S to SW " " " " "
6 = SW to W " " " " "
7 = W to NW " " " " "
8 = NW to N " " " " "
11 = N to NE " greater " " "
12 = NE to E " " " " "
13 = E to SE " " " " "
14 = SE to S " " " " "
15 = S to SW " " " " "
16 = SW to W " " " " "
17 = W to NW " " " " "
18 = NW to N " " " " "

Elevation of receiving station:

0. No data.
1. Hill.
2. Plain
3. Valley

Wires:
0. No data
1. Trolley wires
2. Power wires
3. Signal wires
4. Trolley and power
5. Trolley and signal
6. Power and signal
7. All three

Intensities:
0. No signal
1. Small
2. Medium
3. Large

Fading:
0. No fading
1. Very slight fading
2. Medium fading
3. Bad fading (slow)
4. Bad fading (rapid)

Static - Strays ("static")
0. No static
1. Very slight
2. Medium
3. Bad (frequent)
4. Bad (infrequent)

Weather:
1. Clear
2. Cloudy
3. Rain
4. Snow
5. Sleet
6. Fog
7. Lightning

Rain:
0. No rain
1. Rain

Clouds:
0. None
1. Here
2. Were present
3. Were and are present

Barometer:
1. Rising
2. Stationary
3. Falling.

Barometric gradient:
1. Up gradient
2. Along isobars
3. Down gradient.

Temperature gradient:
1. Up gradient
2. Along isotherms
3. Down gradient.

Appendix II.

Radio Distance Range Tests Tabulation Code.

The table below shows the information contained on a card describing a particular observation by a given observer on a given transmitting station as used in the radio distance range tests. Numbers not in parentheses refer to column numbers on the tabulation card; those in parentheses refer to numbers in the columns.

Table 1.-- Summary of Range Test Data
(as punched on cards for tabulation)

1-2-3-Transmitting station number

4-5-6-7-Receiving station number

8-9 Intervening distance in miles

(01)	0-15	(08)	200-300	(15)	900-1000	(22)	3000-3500
(02)	15-25	(09)	300-400	(16)	1000-1250	(24)	3500-4000
(03)	25-50	(10)	400-500	(17)	1250-1500		
(04)	50-75	(11)	500-600	(18)	1500-1750		
(05)	75-100	(12)	600-700	(19)	1750-2000		
(06)	100-150	(13)	700-800	(20)	2000-2500		
(07)	150-200	(14)	800-900	(21)	2500-3000		

10-11-12-13-14 Date, number system, i.e., 06/01/22

15. Hour (Standard time at the receiving station)
(1) 9 a.m. - 3 p.m. (4) 9 p.m. - 3 a.m.
(2) 3 p.m. - 6 p.m. (5) 3 a.m. - 6 a.m.
(3) 6 p.m. - 9 p.m. (6) 6 a.m. - 9 a.m.

16. Strength of strays.
(1) None (3) Bad (5) Local lightning
(2) Slight (4) Very bad

17. Severity of fading
(0) No data (2) Slight (4) Very bad
(1) None (3) Bad

18. Average strength of signal from station under test.
(1) Not heard
(2) Weak
(3) Strong
(4) Very strong

19. Average readability through all interference.
(1) Not readable
(2) Just readable or occasionally readable.
(3) But little difficulty
(4) Easily readable.

20. Greatest obstacle to reception
(0) Nature of obstacle not known
(1) No obstacles
(2) Atmospherics
(3) Fading
(4) Amateur spark
(5) Amateur CW and phone
(6) Commercial stations
(7) Broadcast stations
(8) Other receiving stations
(9) Power lines, etc.

21. Weather
(1) Clear
(2) Partly cloudy
(3) Very cloudy
(4) Fog
(5) Rain
(6) Snow
(7) Sleet

22. Not used.

23. Detector and circuit.
(1) Single-circuit crystal
(2) Two-circuit crystal
(3) Single-circuit with tube detector (non-regenerative)
(4) Two-circuit with tube detector (non-regenerative)
(5) Single-circuit with tube detector (regenerative)
(6) Two-circuit with tube detector (regenerative)

24. Audio-frequency amplification
(1) No amplification
(2) One step amplification
(3) Two steps amplification
(4) Three steps amplification

25. Radio-frequency amplification.
(1) No amplification
(2) One step amplification
(3) Two steps amplification
(4) Three steps amplification

26. Location of station
(1) On a hill
(2) In a valley
(3) On a plain

27. Immediate surroundings.
(1) No building near (open country)
(2) Buildings of moderate height (residential district)
(3) High buildings (business districts)

28-29. Antenna equipment.
(11) Coil antenna

28. Height in feet
(2) 0-20 feet
(3) 20-30 "
(4) 30-40 "
(5) 40-50 "
(6) 50-75 "
(7) 75-100 "
(8) Over 100 "

29. Length in feet.
(2) 0-50 feet
(3) 50-75 "
(4) 75-100 "
(5) 100-125 "
(6) 125-150 "
(7) Over 150 "

Using this summary, the reader can see that Fig. 2 shows a card punched for an observation on transmitting station 301 taken by observer 8305 whose distance is between 200 and 300 miles. The data were taken September 17, 1922, between 6 and 9 pm. There were no strays. Fading was slight. Signals were very strong and readable with little difficulty, the greatest obstacle being interference from other broadcasting stations. The weather was clear. The operator was using a two-circuit electron tube detector set with two steps audio-frequency amplification, but no radio-frequency amplification. His station was located on a hill in a residential district and his antenna was between 50 and 75 feet high and 100 to 125 feet long.

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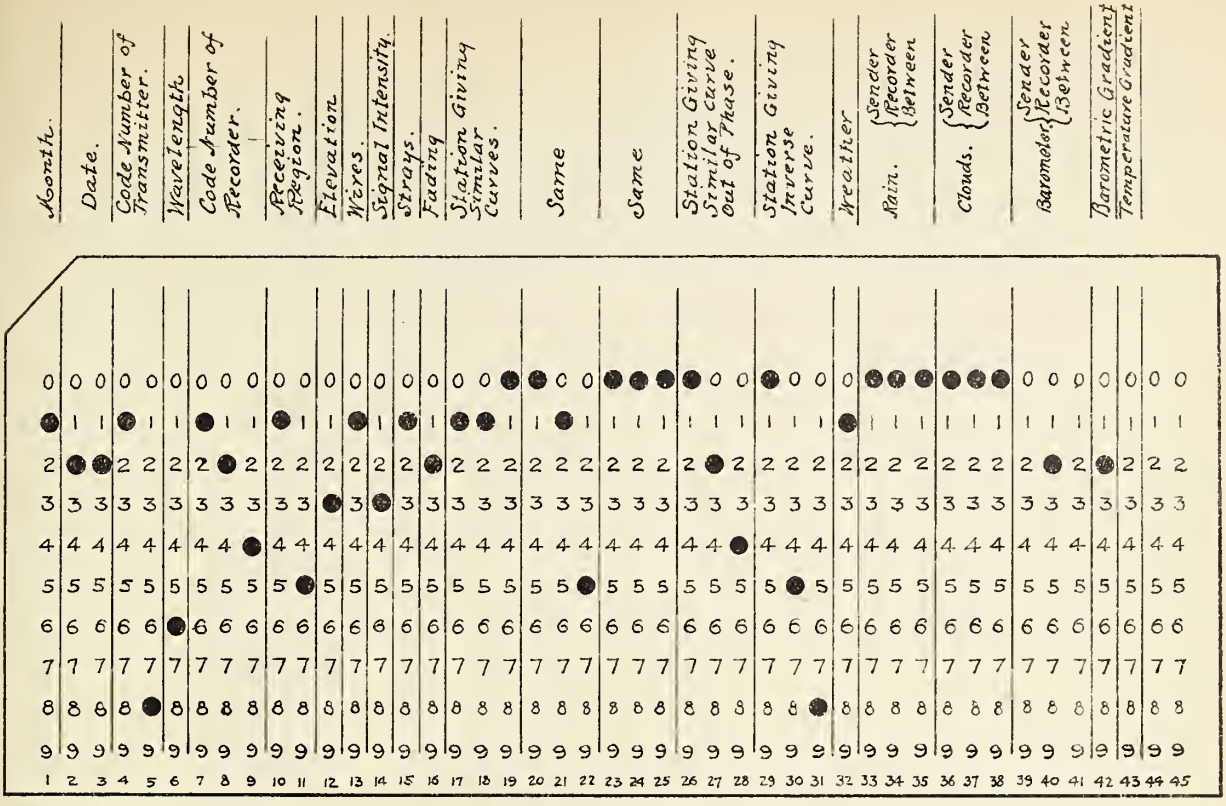

FIG. 1.

STANDARD TABULATING MACHINE CARD USED IN FADING TEST ANALYSIS.

THE CIRCLES IN EACH COLUMN REPRESENT PUNCHINGS WHICH MAY BE INTERPRETED BY REFERENCE TO THE ATTACHED CODE SHEETS.

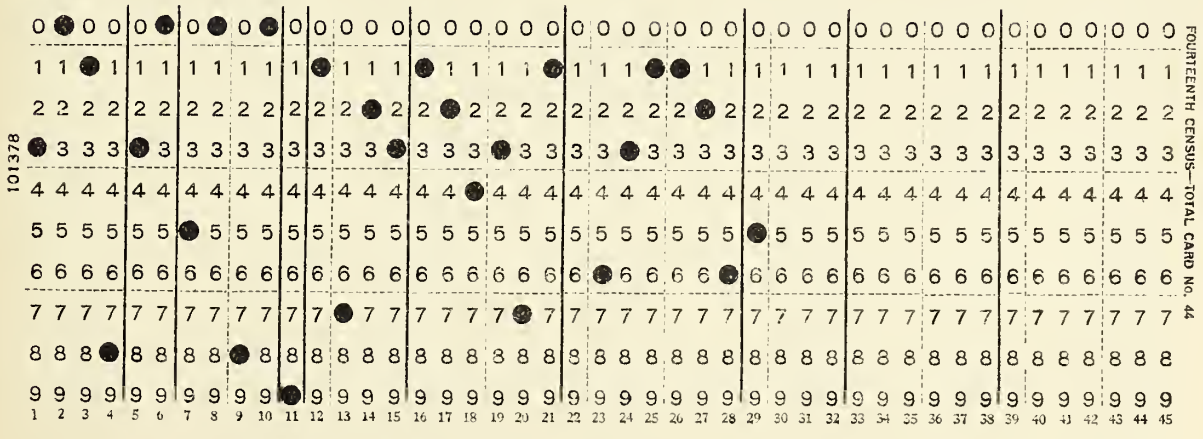

Fig. 2. Card Punched for Analysis of Data.